Wireless Protocols Comparison to Improve the Performance of Intelligent Traffic Light Junctions

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Abstract

Intelligent traffic light junctions management represents a non-trivial problem to be tackled to improve mobility in big crowded cities. In the last few year, the Wireless Sensor Networks (WSNs) have frequently been implicated in Intelligent Transportation System scenarios, primarily in the dynamic management of signalized intersections. In fact, the information concerning traffic light junctions that the WSNs collect in real-time can be a compelling solution to traffic congestion issues. In this paper, a wireless network architecture is presented with the aim to monitor vehicular traffic flows near to traffic lights. Furthermore, an intelligent algorithm is introduced to manage dynamically the phase sequence and the green times of traffic lights considering the estimated values of traffic flows. Several simulations compare IEEE 802.15.4/ZigBee, Bluetooth, and UWB protocols to recognize the proper wireless communication protocol for ITS purposes.

Keywords: Wireless Sensor Networks, Road Monitoring, Traffic Lights, Intelligent Transportation Systems

1 Introduction

The number of vehicles is constantly growing both in small and large cities. One of the main aims of the Intelligent Transportation Systems (ITSs) is to guarantee the efficiency of roads, particularly when traffic jams are very likely to occur; for instance, in traffic lights junctions. In fact, the ITSs purpose is to manage better the traffic condition by improving the safety [4]. This goal, if reached, can determine the minimization of travel time [17] and, as a consequence, of fuel consumption [13]. Although many researchers focused on these issues, today most of the adopted solutions are very expensive and difficult to install and manage [16]. One of the most important aspects on which investigate is represented by the communication medium used to exchange the gathered information about the road [9]. Usually, the devices used to collect road data send the information to a central entity, or to a neighbor device, through the use of wired connections. Today, many researchers of different fields discuss the possibility to replace, wholly or at least partially, the wired networks with the wireless [10] ones for these reasons:

- low cost of wireless devices [5];
- ease of installation [14];
- flexibility [7]: wireless networks can be used, at the same time, for several purposes and, thanks to the possibility to create several types of services, it is possible to manage data traffic flows based on their real-time constraints properly;

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- fault tolerance [11]: the failure of one or more network nodes does not affect the functioning of the entire network;
- scalability [12]: it is quite simple to add or remove a network nodes.

Furthermore, wired networks need the power grid to work. As a consequence, it may be challenging to install these systems in areas hard to reach or where there is no power available. These drawbacks cab be avoided by the evolution of embedded systems, wireless technologies and Wireless Sensor Networks (WSNs), characterized by their low size, ease of installation. Moreover, thanks to their wireless communication, they offer scalability with inexpensive costs. Several works in literature have presented the different advantages provided by the use of wireless technologies in ITS scenarios [15, 8, 2], such as the reduced costs of installations, the better flexibility, the ability to easily realize temporary deployments (e.g. for monitoring purposes), and so on.

Several issues strictly related to ITS, such as data reliability, communication security, interoperability, scalability, real-time communication, can be addressed through innovative ideas that may individually, or in a complementary manner, cover the following aspects:

- design of multi-tiered network architectures: often it is necessary to organize the road areas to be monitored in cells. As a consequence, it is essential to provide mechanisms and protocols to ensure the interconnections among cells. Another aspect to consider is represented by the need to ensure the possibility to realize systems aimed to ease the integration of different devices designed to work for specific and different tasks;
- implementation of new mechanisms, or protocols, to improve/ensure the reliability of communications on ITS solutions;
- development of techniques to support the transmission of real-time constrained data.

This work presents a network architecture for intelligent management of traffic light junctions. Specifically, this paper shows an implementation of the proposed architecture both on IEEE 802.15.4 [1], Bluetooth [3] and UWB [6] networks to determine the best technology meeting the requirements that characterize road monitoring environments. Furthermore, in this paper, an algorithm for the intelligent and dynamic management of traffic lights is also introduced.

2 The Proposed System Model

2.1 Network Architecture

The proposed architecture, depicted in Figure 1, is a hierarchical network distinguished by two layers: the first is identified by a wireless sensor network, based on the IEEE 802.15.4/ZigBee, Bluetooth or UWB, while the second consists of a wired backbone. The designed two-tiered architecture is valid for a generic road intersection. Considering the IEEE 802.15.4/ZigBee protocol [1], for each intersection, several Reduced Function Device (RFD) sensor nodes, arranged in clusters and regulated by special Full Function Device (FFD) nodes, are employed. The entire network is managed by a sink node that receives and handles all data regarding the number of vehicles. The sink nodes are connected through a wired backbone to a central controller. Each IEEE 802.15.4/ZigBee cluster is composed of an FFD node and several RFD nodes. The FFD node is an IEEE 802.15.4 cluster coordinator, and it also takes care of routing among groups. Regularly, the FFD node transmits a data inquiry to its RFD nodes. These nodes respond to the request by transmitting the gathered data. Each RFD node can detect vehicles in transit, using magnetometers.

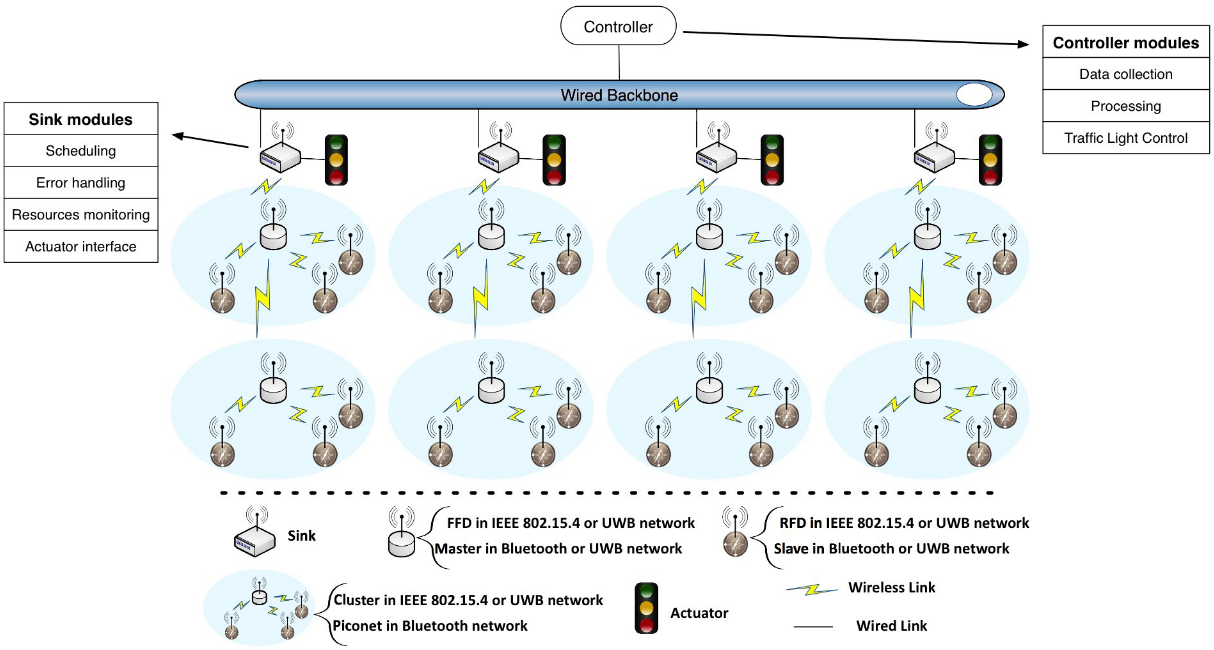

Figure 1: Proposed network architecture.

Regarding Bluetooth [3], a Piconet is composed of a Master node and a number of Slaves equal to 7. If the network expects more than 7 Slaves, then it is feasible to realize a Scatternet, an ad-hoc computer network consisting of two or more Piconets. In this case, there is a Slave that transmits data among members of both nets. Considering the Figure 1, in the Bluetooth approach, the traffic light junctions are monitored using appropriate sensors nodes (Slaves) and the data gathered by them is then forwarded to their Piconet Master which accumulate data of the Piconet and transmit them to the sink which takes care of data exchanging between Piconets.

UWB [6] differs from other Radio Frequency (RF) and Spread Spectrum (SS) by using a wide band of RF spectrum to send data. In this way, UWB can send more data in a given period thus achieving a higher data rates compared to other technologies. When UWB transmits over a broad bandwidth with low power, the signal does not interfere with other wireless transmissions. Traditional UWB transmitter sends billions of signals across a vast spectrum of frequencies. The receiver listens to specific pulses in the signal and translates those into data. Current UWB systems employ other modulation techniques to utilize these extremely wide bandwidths. The basic operation of UWB is to send signals to a broad spectrum and low powers. In fact, except for UWB receivers, the signal appears as noise. Considering the Figure 1, the network architecture is similar to the other two wireless protocols, i.e. there is a centralized node (FFD or Master) and several distributed nodes (RFD or Slave).

As shown in Figure 1, each approach is provided with a sink node, which performs several tasks described below. Specifically, the Scheduling module manages networks real-time traffic, allows bandwidth reservation and avoids collisions. The Error Handling module manages the errors in data transmission. The Resources Monitoring module controls and assigns the availability of resources, for instance by regularly evaluating the quality of wireless channels. The Actuator Interface module handles the transmission with the actuator, by forwarding commands for the timing of lighting and the closedown of the traffic lights optical units. Periodically, the sink node collects data from sensors and sends them via the

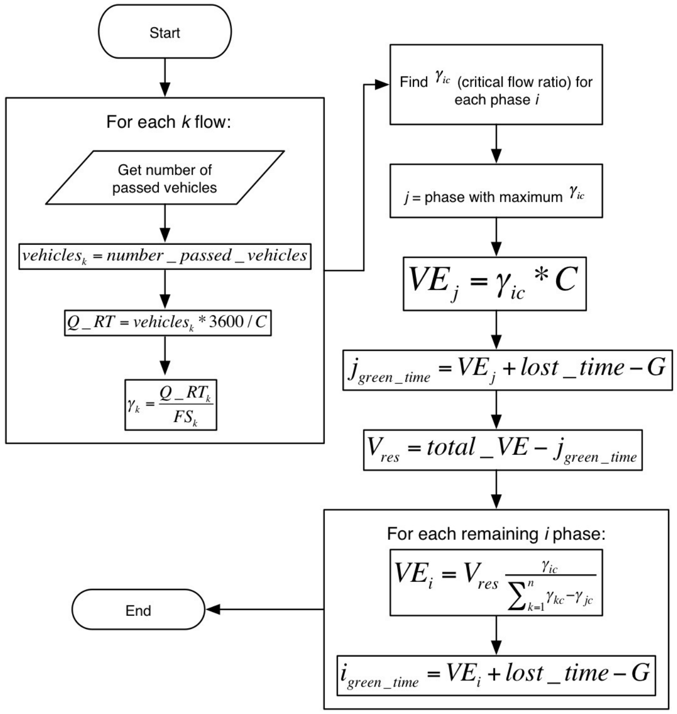

Figure 2: Green times calculation flowchart.

wired backbone to the network controller. This Controller is composed of several modules to realize the data collection, the data processing, and the traffic lights control. The Data Collection module acquires and prepares data sent by sink nodes. The Processing module examines data developed by Data Collection module and treats them trough an appropriate algorithm. This algorithm manages the received data to determine the phase sequence and the green time of each phase. The algorithm uses several parameters, such as the number of vehicles in transit and the width of the queue for several lanes. Finally, the Traffic Lights Control module uses the results produced by the algorithm to handle the duration and the sequence of traffic light phases, by sending commands to the sink. These data are then forwarded to the actuator.

2.2 Intelligent Traffic Light Manager Algorithm

The dynamic traffic light management allows runtime and real-time regulation of green times duration and phase sequence, taking into account the data gathered by a WSN deployed on the road. The proposed intelligent management algorithm is distributed into two steps. In the first step, the phase sequence is determined. In fact, the algorithm, based on the queue length for each flow (input variable), assigns a priority to each phase equal to the maximum queue length of that phase. Finally, it determines the phase sequence by ordering the queues in decreasing order priority. In the second step, the algorithm accomplishes the green time's calculation. In fact, the proposed algorithm, for each flow, evaluates the number of vehicles crossed during the previous traffic light cycle and utilizes this value to determine the current traffic volume (Q_RT). This value is applied to recalculate the green time duration of the next cycle based on the detected traffic. Figure 2 presents the flowchart of green times calculation.

The flow ratio γ for a generic flow i is defined as the ratio between the actual or expected incoming stream Q (or volume) and the saturation flow rate FS:

$$\gamma_i = \frac{Q_1}{FS_i} \tag{1}$$

Data arriving from the WSN is utilized to determine the incoming stream at every traffic light cycle. In fact, for each lane, the number of vehicles crossed in each cycle is calculated. This data is turned into vehicles/h and consequently applied to estimate the flow ratio for each traffic flow. Moreover, for every phase, the critical lane (i.e. the one with the higher flow ratio) is set. As a consequence, the phase with the highest flow ratio is determined; to this j-phase a saturation flow ratio equal to 1 is assigned, giving the rests to the remaining phases in proportion to their flow ratios:

$$\frac{VE_j}{C} = \gamma_i \tag{2}$$

where VE_j is the effective green time for the j-phase and C is the traffic light cycle duration. Once VE_j is achieved, it is possible to determine the green time (V) of the j-phases using the following equation:

$$V_j = VE_j + P - G \tag{3}$$

where P is the lost time due to start-up and permission times, while G is the yellow time. The seconds available for remaining phases are measured as follow:

$$V_{res} = \sum_{j=1}^{n} VE_j - V_j \tag{4}$$

For remaining green time (V_{res}) allocation, the following equation can be used:

$$VE_j = V_{res} \frac{\gamma_{iC}}{\sum_{k=1}^{n} \gamma_{kC} - \gamma_{jC}} \tag{5}$$

Finally, the green time for each i-phase is calculated using the equation 3.

3 Performance Evaluation

To validate the benefits introduced by the proposed solution considering both IEEE 802.15.4, Bluetooth and UWB, several simulations have been carried out. Regarding IEEE 802.15.4 and UWB, the simulations have been conducted using OMNeT++ considering several cluster topologies consisting of an FFD and 7 RFD. The same topology has been used for measurements concerning a Bluetooth network, i.e. a Master and 7 Slaves forming a Piconet. In this case, simulations have been carried out through the ucbt extension of NS-2 simulator. In both cases, the Throughput/Workload (Th/Wl) percentage and the average delay related to periodic/aperiodic flows have been measured considering a packet size of 18 KB and data rate of 180 kbps for each network node. The periodic flows (packets) refer to the monitoring of network resources and to the data collected by sensor nodes. On the contrary, aperiodic flows deal with the error handling and the scheduling.

Figure 3 shows a comparison between the results achieved in IEEE 802.15.4/ZigBee, Bluetooth, and UWB, respectively. It is feasible to note that the IEEE 802.15.4 network provides the best performance. In fact, the periodic Th/Wl percentage measured is 81.7% against 67.2% measured in a Bluetooth scenario and 70.4% in UWB one, while aperiodic Th/Wl percentage achieved is 16.3% against 21.8% and 15.5% obtained in a Bluetooth and UWB scenarios respectively. Regarding the delay, as shown in Figure

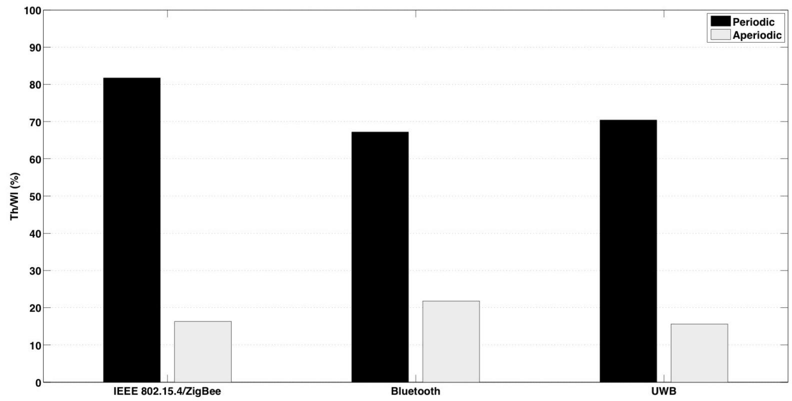

Figure 3: Th/Wl behavior comparison.

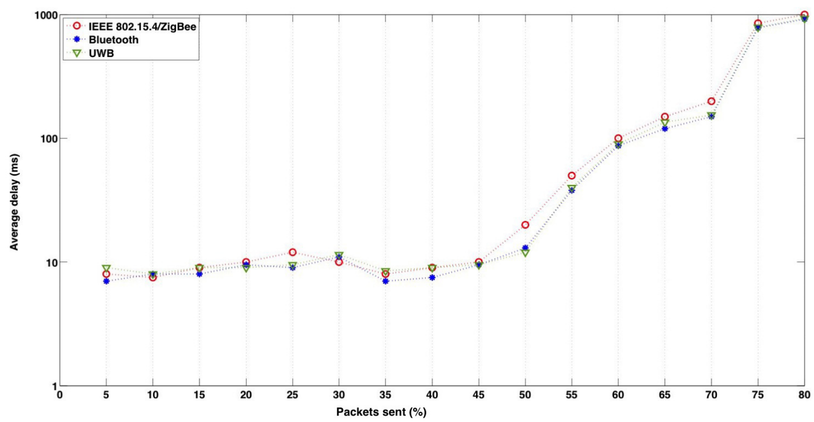

Figure 4: Average delay.

4, it is possible to conclude that Bluetooth produces on average a delay of 16.81 ms lower than IEEE 802.15.4/ZigBee and 3.16 ms lower than UWB.

Furthermore, other simulations have been carried out to determine the performance of the algorithm for the intelligent and dynamic management of the traffic light. The simulations have been performed in cases of fixed and dynamic traffic light cycles to demonstrate the goodness of the proposed solution. Each simulation produces an average queue length trend for the traffic light cycles. Traffic volume levels set in the different case studies are the following:

- simulation 1 = low traffic volume;
- simulation 2 = medium traffic volume;
- simulation 3 = high traffic volume.

The obtained results, depicted in Figure 5, show a reduction of average queue length in each case study with dynamic management.

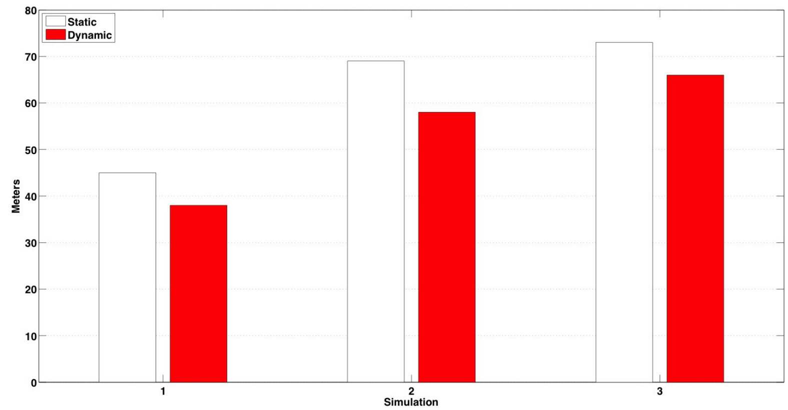

Figure 5: Average queue length – comparison between static and dynamic management.

4 Conclusions

In this paper, a Wireless Sensor Network architecture, with multiple levels and based on IEEE 802.15.4/ZigBee, Bluetooth or UWB protocols, for intelligent traffic flows monitoring has been proposed. A comparison between IEEE 802.15.4/ZigBee, Bluetooth, and UWB solutions has been carried out to recognize if they are communication protocols suitable for ITS applications. The simulation results show that the considered wireless protocols behave well enough in the ITS context. Moreover, in this paper, an algorithm for the dynamic management of intersections that use data collected by the WSN, to determine the phase sequence and the green time's duration, has been implemented. The obtained results demonstrate that it is possible to achieve a better management of isolated traffic light junctions using the proposed algorithm.

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Author Biography

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Alessandro Severino graduated in Architecture and Engineering at Kore University in Enna, Italy. Since 2015, he is a Ph.D. student and is working on a research project named ”Urban Infrastructures for the Territory”. The title of his research project is “ Eco-Design of Building Infrastructures for the new Sicilian Railway System.” His research interests include intelligent transportation systems, traffic light management, inter-vehicle and vehicle-to-infrastructure communications, traffic operations administration and control.

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